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Effect of jet-cooked wheat gluten/lecithin blends on maize and rice starch retrogradation☆

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Abstract

Vital wheat gluten and lecithin (GL) (50:50, w/w) were dry blended in a coffee grinder and a 9.5% (w/v) aqueous slurry was jet-cooked (steam pressures of 65 psi/g inlet and 40 psi/g outlet) to disaggregate wheat gluten and facilitate better dispersion of the two components. The jet-cooked material was freeze-dried and stored at 0 °C for future use. The GL blend was added to pure food grade common maize and rice starch at concentrations of 0 (control), 6, 11, 16, and 21%. Starch gelatinization and retrogradation temperature transitions were determined using Differential Scanning Calorimetry (DSC). From the DSC profiles, the change in the ΔH value was used as an indication of starch retrogradation, where a higher ΔH value indicated higher retrogradation. The ΔH values of the blends at 4 °C had higher values than the −20 °C and the ambient (25 °C) storage temperatures. Overall, the 21% GL/starch blends reduced retrogradation by 50%. The lower amylose content of rice starch relative to maize starch was reflected in Rapid Visco Amylograph (RVA) measurements of peak viscosity, and similarly, Texture Analyzer (TA) measurements indicated that maize starch gel is firmer than rice starch gel. Retrogradation was also evaluated by observing G', the shear storage modulus, as a function of time after running a standard pasting curve. Using this method, it appears that GL has a significant effect on maize starch retrogradation, since low concentrations (<0.4%, w/w) reduced G' up to 40%. The opposite behavior was seen in rice starch, where G' increased directly with added GL. It appears that the amylose level in the rice starch is too low to be affected by the GL, and the increase seen in G' is most likely due to added solids.
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Keywords: Jet cooked; Lecithin; Maize starch; Rice starch; Retrogradation; Gel firmness

1. Introduction

Starch retrogradation has been a subject of much research in the food industry. Retrogradation of starch occurs when the amylose in starch-containing products returns to a less soluble, crystalline state over time. Retrogradation of various types of starches, such as potato (Karlsson and Eliasson, 2003), rice (Chang and Liu, 1991), wheat (Jankowski and Rha, 1986), and amaranth (Baker and Rayas-Duarte, 1998b), has been studied and a number of approaches used to eliminate or reduce this phenomenon.

The effects of sugars and salt on retrogradation have been reported extensively (Baker and Rayas-Duarte, 1998b; Cairns et al., 1991; Chang and Liu, 1991; Ciacco and Fernandes, 1979; Kohyama and Nishinari, 1991; I'Anson et al., 1990). Sugars and salt can increase or decrease retrogradation, depending on the type of sugar and/or starch used for analysis. Sugars and salt also have an effect on the freeze–thaw stability of starch (Baker and Rayas-Duarte, 1998a). Retrogradation increases with time in food products such as bread (Krog et al., 1989). The rate and extent of starch retrogradation is affected by the length of time a product is stored and the temperature of storage (Colwell et al., 1969; Eliasson, 1983; Longton and LeGrys, 1981; McIver et al., 1968; Nakazawa et al., 1985). Bread staling is a complex phenomena which involve both the amylose and amylopectin components of starch. A number of hypotheses have been proposed to explain bread staling. The most common theory implicates the formation of amylopectin

☆ Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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crystallites, whereas some researchers implicate amylose (Hoseney and Miller, 1998).

Differential scanning calorimetry (DSC) has become a commonly used technique for analyzing the gelatinization of starch and the study of its retrogradation (Baker and Rayas-Duarte, 1998b; Chang and Liu, 1991; Eliasson, 1983; Jankowski and Rha, 1986; Karlsson and Eliasson, 2003; Krog et al., 1989; Miles et al., 1985; Nakazawa et al., 1985; Ribotta et al., 200; Roulet et al., 1990; Russell, 1987; White et al., 1989; Zeleznak and Hoseney, 1987)

Studies of wheat protein (gluten) and starch interactions have shown that wheat gluten can bind to the surface of starch granules and alter their physical and thermal properties (Dahle, 1971; Dahle et al., 1975; Eliasson and Tjerneld, 1990). When starch is gelatinized in the presence of wheat gluten, the protein affects the gelatinization enthalpy (ΔH) of the starch, as well as its interaction with water (Eliasson, 1983; Mohamed and Rayas-Duarte, 2003). Rheology has been used to study the flow properties of wheat flour (Xu et al., 2001), the effect of heat damage on wheat flour (Mohamed et al., 2004), and the effect of amylopectin on the thermal properties of soy protein (Mohamed and Xu, 2003).

Lecithin, a by-product of the soybean processing industry, has many food and non-food applications. One of its primary uses is to retard amylose retrogradation and prolong the shelf life of baked products. The current market price for lecithin is \$5/lb. Vital gluten, a by-product of the wheat starch industry, costs \$0.65/lb. Gluten is a hydrophobic insoluble biopolymer with a molecular weight in the millions. Jet-cooking of a dilute wheat gluten suspension may cause polypeptide extension and increase the exposure of hydrophobic regions. Exposed hydrophobic regions become available for dispersion by the hydrophobic end of lecithin to produce a homogeneous suspension. In this study, a jet-cooked blend of vital wheat gluten and lecithin (GL) was mixed at various levels with pure food grade maize starch and common rice starch. The use of GL blend to retard amylose retrogradation has the advantages of being easier to use, nutritionally advantageous, and cheaper to prepare than the commonly used methods of amylose retrogradation prevention, such as starch chemical modification.

2. Materials and methods

2.1. Materials

Pure food grade maize starch was obtained from A.E. Staley, Inc. (Decatur, IL). Common rice starch was obtained from Remy Industries (Leuven, Belgium). The starches were used as received. The amylose content of the starches was determined according to Sievert and Holm (1993) using DSC. The amylose standard was from Megazyme (Megazyme International Ireland Ltd, Bray Co., Wicklow, Ireland) and lysophosphatidylcholine from Sigma (Sigma Chemical Co., St Louis, MO). Vital wheat gluten was obtained from Midwest Grain Products (Pekin, IL), and lecithin granules were obtained from Bulk Foods (Toledo, OH). Vital gluten was used as is without further purification. The lecithin was ground using a Black and Decker SmartGrind coffee grinder (Miami Lakes, FL), and sieved through a 40-mesh screen before further use.

2.2. Preparation of vital gluten–lecithin (GL) blends

A dry blend of wheat gluten and lecithin (50/50, w/w) was homogenized using a coffee grinder. A slurry of the 50/50 homogenized blend was prepared by adding 280 g of the blend to 3 l deionized water and then mixing in a Waring blender. The resultant slurry was jet-cooked for 3 min in a pilot plant scale, excess steam jet cooker (model number G-HD, Hillside, NJ). The inlet pressure was set to 65 psi, the outlet pressure was 40 psi, and the steam temperature was 125–140 °C. The jet-cooked slurry was cooled to 25 °C in an ice-water bath, freeze-dried and then blended with the coffee grinder.

2.3. Differential scanning calorimetry (DSC)

The jet-cooked gluten–lecithin and starch mixes were made by weighing the appropriate amount of each dry material. A total sample weight (1 g) was made using percentages of 0% (control), 6, 11, 16 and 21% of jet-cooked material added to maize and rice starch, where the amount of starch was the same in all samples. The mixes were stirred thoroughly with a spatula, then covered with Parafilm (Sigma, St Louis, MO) and stored at room temperature. Samples were prepared for the DSC as described by Baker and Rayas-Duarte (1998a,b). Samples (5 mg) were weighed into an aluminum, polymer-coated DSC pan (TA Instruments, New Castle, DE). Millipore water (10 μl) was added, and the pan was hermetically sealed and allowed to equilibrate for 2 h. All samples were gelatinized on the 2920 Modulated DSC (TA Instruments) by scanning at a rate of 10 °C/min from 30 to 120 °C. Samples, after DSC gelatinization, were then stored using several different parameters: temperature (ambient, 4 or −20 °C), time (2, 7, 15, or 21 d), and the percentage of jet-cooked material in the mix (0, 6, 11, 16, or 21%). After the appropriate storage period for each sample had passed, the sample was removed from the storage area (4 and −20 °C) and allowed to equilibrate for 30 min. Samples were then analyzed for retrogradation using the DSC at a rate of 10 °C/min from 20 to 120 °C. Three replicates of each sample were analyzed.

2.4. Water hydration capacity (WHC)

Thermogravimetric analyses (TGA) were made by adjusting the moisture content of pure lecithin, gluten, and jet-cooked 50:50 gluten–lecithin blend. Samples (20 mg) were adjusted to 20% moisture, loaded on the TGA 2050 Thermogravimetric Analyzer (TA Instruments, New Castle, DE), heated at 10 °C/min from 25 to 150 °C, and held for 60 min at 150 °C. The water hydration capacity (WHC) of gluten, lecithin, and jet-cooked GL blend was determined according to Approved Method 56-30 (AACC, 2000) with the following modification: the weight of the sample used for the WHC measurement was corrected based on each sample's actual moisture content,

whereas the AACC method is based on 14% moisture. Each WHC measurement was replicated three times.

2.5. Syneresis

Gels used for syneresis of starches and starch–GL blends were prepared using a Rapid Visco Analyzer Model RVA-4 (Newport Scientific Ltd, Warriewood, Australia). Samples (3 g) were brought to 28 g total weight using distilled water. Each sample was stirred initially at 960 rpm for 10 s and 50 °C to remove any lumps. The stirring rate was then adjusted to 160 rpm, and after an equilibration time of 1 min, the samples were heated at a rate of 10 °C/min to 95 °C, held at 95 °C for 2 min and then cooled at 10 °C/min to 50 °C. The paste (30 ml) was transferred to 50 ml centrifuged tubes. The tubes were centrifuged after storage for 15 min at 900 *g* and the amount of separated water was collected and expressed as percent of the total weight of the gel.

2.6. Gel pasting properties and firmness

Pasting property analysis was prepared using the 'native starch' method preloaded on the RVA version 2 software package. Starch blend samples (3.5 g, 14% mb) were weighed and nano-pure water was added to obtain a total of 28 g. The pasting profile was identical to that described in Section 2.5. The pasting temperature, peak viscosity, time to peak, breakdown, minimum viscosity, setback and final viscosity were recorded.

Gel firmness measurements were made on samples obtained from the RVA analysis and stored at 25 and 4 °C. A Texture Analyzer TA-XT2i (Texture Technologies Corp., Scarsdale, NY) equipped with a 6 mm cylinder probe and 5 kg load cell was used. Warm gels from the RVA were transferred to 50 ml glass beakers (50 mm high, 38 mm diameter); gels in the beaker were 20 mm high. The upper surface of the gel was gently smoothed out and tested while in the beaker. Gels in testing beakers were allowed to cool for 30 min before sealing with parafilm and storing at 25 °C for 24 h before analysis. An identical set of samples was stored at 4 °C for 19.5 h and equilibrated to 25 °C for 4 h prior to analysis. The force of compression was obtained using the following testing parameters: (a) 2.0, 0.5 and 2.0 mm/s for pre-test, test and post-test speed, respectively; (b) 4 mm distance; (c) auto-5 g trigger type; and (d) 10–50 pps data acquisition rate.

2.7. Rheology

Samples contained 5% maize or rice starch solids (1.5 g starch in 30 g total) and the added GL ranging from 0.1–1.2% (w/w). For each sample, the two dry ingredients were weighed first, and then the total weight was brought to 30 g by adding water.

The pasting profile and gelation/retrogradation studies were performed on the same instrument; a TA AR2000 rheometer (New Castle, DE) using a starch pasting cell fixture. The pasting profiles of the starch/GL blends were determined as follows: An initial mixing step at 750 rpm was applied for 30 s at 25 °C. Then, a linear temperature increase of 5 °C/min was applied until the sample reached 95 °C. During this step and for the remainder of the pasting profile, the mixing head rotated at 100 rpm. At 95 °C, the sample was held for 5 min, and then the temperature was decreased linearly at 5 °C/min to 25 °C. At this point, the blend was subjected to an oscillatory time sweep test and oscillated at 0.5% strain for a minimum of 10 h.

The starch pasting cell allows the instrument to record typical pasting temperature profiles as well as many rheological parameters within the same sample cell. Thus, the instrument has the advantage of being able to immediately begin the time sweep experiment after the pasting profile and there is no perturbation of the sample in transfer from one instrument to another. Since the starch pasting cell uses a propeller-shaped mixing head (as opposed to cone and plate, parallel plate, or some other analytically derived geometry), determination of rheological parameters such as G' and G'' is made through a calibration constant of a Newtonian reference fluid and therefore is not completely rigorous. However, all the maize starch blends were measured using this geometry so comparison between them is possible.

2.8. Statistics

A completely random design (CRD) was used to compare the two starches at different temperatures, protein levels, and during storage. Levene's homogeneity of variance tests at the 5% alpha level were performed to determine if data transformations of the dependent variables were necessary to stabilize the variance before ANOVA (analysis of variance) could be run. If a significant *F*-test value was obtained from the ANOVA for protein, pairwise multiple comparison tests were performed using Duncan's multiple range test at the 0.05 level. If a significant *F*-test value was obtained for either starch or temperature, the significant *p*-value associated with the *F*-test is sufficient for determining differences.

3. Results and discussion

Maize and rice starch had amylose contents of 24.3 ± 0.6 and 19.6 ± 0.2%, respectively. The ΔH value as determined by DSC was used to indicate the degree of amylose/amylopectin retrogradation in the presence of different levels of gluten–lecithin (GL) blend after gelatinization and storage at different temperatures for different periods. A DSC run of the pure gluten–lecithin blend (50% moisture content) was obtained to eliminate any possibility of transitional overlap with the native starch gelatinization transition. The pure GL blend profile showed two transitions: the glass transition (T_g, middle temperature 87.5 °C and 0.174 J/g/ $°C^{-1}$) and an endothermic transition at 199 °C with ΔH 14.8 J/g, which is much higher than the range for most cereal starch gelatinization temperatures (60–70 °C) (Fig. 1). The DSC profile of the stored starch gels is shown in Fig. 2 for comparison. It is clear from the profile that the endothermic transition around 55 °C is far from

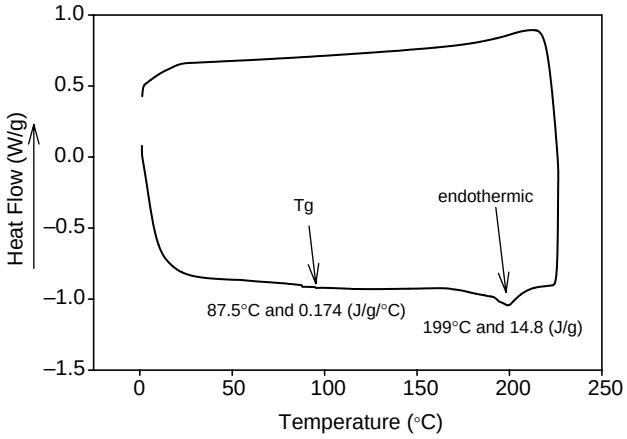

Fig. 1. DSC profile of gluten–lecithin (GL) at 50% moisture content.

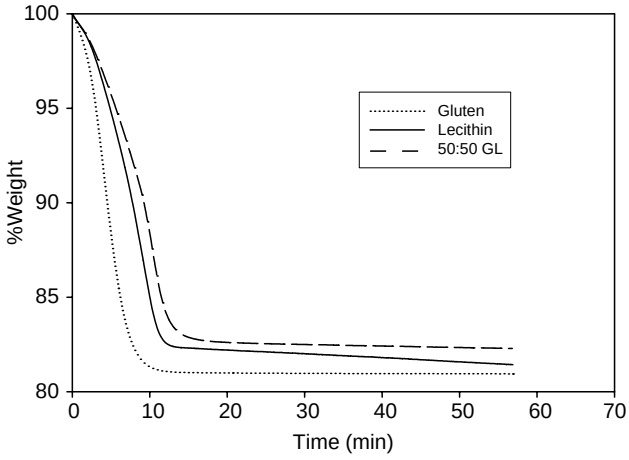

Fig. 3. Thermogravimetric analysis (TGA) of gluten, lecithin, and 50:50 GL blend at 20% moisture content.

the GL blend transition. This transition also occurred at a much lower temperature than the amylose–lipid complex transition.

Summarizing the data, it appears that storing gelatinized maize starch samples at 4 °C caused significantly more retrogradation than the ambient or −20 °C ($p<0.0001$) samples. Higher levels of GL showed a significant reduction in ΔH, indicating lower starch retrogradation ($p<0.0001$) except between 16 and 21%. After 2 and 7 d storage, lower retrogradation levels and smaller differences between ambient and −20 °C was observed, whereas at 4 °C retrogradation levels were twice as high as at the other two storage temperatures. It was apparent that retrogradation at ambient temperature and −20 °C was delayed in the samples stored for 2 and 7 d. However, after 15 d storage, a difference was obvious in the samples stored at ambient temperature and −20 °C (Table 1).

For each starch type, the effect of GL level, temperature, and storage time was analyzed separately (Tables 1 and 2). Rapid Visco Amylograph (RVA) testing of the maize and rice starch clearly indicated very different behavior with respect to their pasting properties. After 2 d storage, although the interaction was found to be insignificant, there was a trend to lower ΔH with higher GL levels and lower ΔH at ambient or −20 °C relative to 4 °C (Table 1). For optimum retrogradation, amylose molecules, and to some extent amylopectin, must be mobile enough to re-crystallize, but not so mobile that weak linear associations are overcome by thermal energy. It is possible that storage at 4 °C provided the most favourable of molecular mobility, so that amylose/amylopectin molecules associated more rapidly relative to that at ambient or −20 °C storage temperatures (Ribotta et al., 2003). The effect of GL after 7 d storage showed a similar trend, but the ΔH values were significantly higher than at 4 °C ($p<0.0001$), whereas those at −20 °C and ambient temperature were similar. For storage times of ≥15 d at 4 °C, the same trend continued, and although at ambient temperature there was a significant increase in retrogradation and ΔH values decreased as the level of GL increased (Table 1).

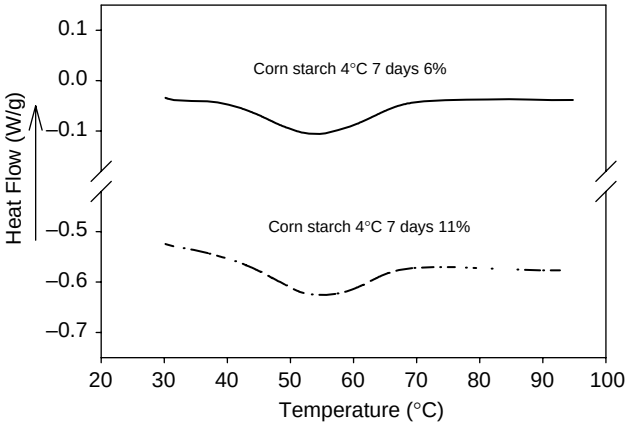

Fig. 2. DSC profile of maize starch gels containing 6 and 11% GL blend stored for 7 d at 4 °C.

As indicated by the ΔH values, the data showed diversity among the samples (Table 2). In general, the presence of GL significantly ($p<0.0001$) reduced retrogradation but there was no clear correlation between the ΔH values and the increase in the percentage of GL added (Table 2). The most noticeable difference was between the 4 °C control samples at 21 d storage, where the ΔH value was six times greater than the −20 °C samples and four times greater than those at ambient temperature (Table 2). This relationship was observed only for 21 d storage, whereas, for the remaining storage days, 4 °C had twice the ΔH value, which is in agreement with the maize starch data. Overall, differences between ΔH values of the control and the GL samples were greater for the maize starch than for the rice starch. This could be due to differences in amylose content and type. As GL content increased, ΔH showed a gradual reduction (Table 2).

The capacity for GL to absorb water expelled from the starch gel during retrogradation (syneresis) was measured in the WHC experiments. This made it possible to determine whether the influence of the GL blend on amylose retrogradation was due to interaction with amylose molecules or to the absorbance of the expelled water. The WHC test showed that lecithin retained 12% water relative to its weight, whereas gluten and jet-cooked GL blend retained 26 and 46%,

Table 1
Effect of storage time, temperature, and gluten/lecithin level on the least square means estimates of ΔH for common maize starch

Days	% G/L[a]	Ambient[b]	4 °C	−20 °C
2 days[c]	0.00	1.196±0.24	4.618±1.26	2.814±2.41
	6.00	1.775±0.99	4.324±0.62	1.330±0.36
	11.0	0.917±0.31	3.617±0.33	2.100±2.25
	16.0	0.840±0.41	2.934±0.43	1.247±0.81
	21.0	3.212±4.60	2.972±0.57	0.981±0.56
7 days	0.00	2.006±1.71cd	6.495±1.27a	2.810±0.56bcd
	6.00	2.404±0.27bcd	5.890±0.41a	1.802±1.14cd
	11.0	1.831±0.38cd	5.176±0.85ab	1.536±0.29cd
	16.0	1.725±0.50cd	4.839±0.66ab	1.004±0.56d
	21.0	1.574±0.49cd	3.887±0.52abc	1.692±1.57cd
15 days	0.00	3.945±0.87abcda	6.041±0.53a	1.584±0.29ef
	6.00	3.020±0.19bcdef	5.687±0.51a	1.416±0.11ef
	11.0	2.497±0.28cdef	5.145±0.57ab	1.523±0.29ef
	16.0	2.221±0.69cdef	4.496±0.39abc	2.074±2.55cdef
	21.0	1.880±0.54def	4.309±0.51abcd	1.018±0.35f
21 days	0.00	4.262±0.52abcd	6.284±0.32a	1.647±0.77ef
	6.00	4.065±1.29bcd	5.789±0.14ab	1.148±0.22ef
	11.0	3.290±0.25cde	5.092±0.45abc	4.646±1.27ef
	16.0	2.716±0.59def	4.834±0.36abc	1.217±0.32ef
	21.0	2.603±0.23def	3.897±1.02fbcd	0.952±0.48f

Estimates within a day followed by the same letter are not significantly different based on difference of least squares means at $p \leq 0.05$.
[a] G/L: gluten–lecithin blend.
[b] ΔH (J/g).
[c] The two days storage data showed no significant difference at $p \leq 0.05$.

respectively. The thermogravimetric analysis confirmed the ability of jet-cooked blends to retain more water than pure gluten and lecithin (Fig. 3). The higher water retention of the jet-cooked material should not affect the amount of water available for starch gelatinization due to the excess water used to prepare the gels.

The gels used at ambient temperature for syneresis displayed a soft texture that obscured the measurement of the amount of water separated during storage. Thus, only the 0, 11, and 21% GL blends with maize and rice starch stored at 4 and −20 °C are reported. Samples stored at 4 or −20 °C showed that syneresis increased from 0.36 to 1.1% for maize starch and

Table 2
Effect of storage time, temperature, and gluten/lecithin level on the least square means estimates of ΔH for common rice starch

Days	% G/L[a]	Ambient[b]	4 °C	−20 °C
2 days	0.00	0.526±0.02bc	1.128±0.28a	0.511±0.44bc
	6.00	0.527±0.06bc	0.797±0.24ab	0.392±0.23bc
	11.0	0.155±0.04c	0.706±0.03abc	0.387±0.21bc
	16.0	0.261±0.03bc	0.640±0.13abc	0.158±0.03c
	21.0	0.121±0.16c	0.397±0.11bc	0.122±0.08c
7 days	0.00	0.870±0.29de	2.594±0.38a	0.692±0.54e
	6.00	0.680±0.12e	2.286±0.18ab	0.501±0.20e
	11.0	0.610±0.14e	1.671±0.09bc	0.425±0.08e
	16.0	0.562±0.10e	1.499±0.14cd	0.338±0.08e
	21.0	0.240±0.35e	1.407±0.32cd	0.235±0.11e
15 days	0.00	1.567±0.21cde	4.186±0.57a	1.313±0.27de
	6.00	1.223±0.14de	3.313±0.72ab	0.875±0.85e
	11.0	1.210±0.14de	3.058±0.92abc	0.862±0.08e
	16.0	0.762±0.33e	2.954±0.26abc	0.563±0.42e
	21.0	0.554±0.18e	2.485±0.65bcd	0.152±0.06e
21 days	0.00	1.214±0.83c	5.214±0.23a	0.846±0.77c
	6.00	1.034±0.14c	4.433±0.76ab	0.672±0.66c
	11.0	0.713±0.03c	3.700±0.10b	0.659±0.27c
	16.0	0.534±0.33c	3.673±0.37b	0.597±0.07c
	21.0	0.620±0.05c	3.399±0.51b	0.444±0.31c

Estimates within a day followed by the same letter are not significantly different based on difference of least squares means at $p \leq 0.05$.
[a] G/L: gluten–lecithin blend.
[b] ΔH (J/g).

Table 3
%Syneresis of maize and rice starch stored at 4 and −20 °C in the presence of 11 and 21% GL

%GL	4 °C		−20 °C	
	Maize	Rice	Maize	Rice
0	0.36±3.4	0.25±6.8	1.10±5.8	54.0±8.40
11	5.30±5.2	0.31±9.5	3.33±4.7	50.2±11.7
21	5.80±7.4	0.80±8.4	1.44±6.1	49.0±12.3

from 0.25 to 54% for rice compared to the control (Table 3). The syneresis values for both starches increased as the percentage of GL increased on storage at 4 °C. Rice starch at −20 °C displayed slightly decreasing syneresis with increasing GL content (Table 3). It appeared that the presence of GL interfered with the ability of amylose to form the network needed for a stronger gel texture, and as a result, a softer gel with less capacity to hold water was formed. No trend was evident for maize starch at −20 °C.

The peak viscosity of maize starch, as measured by the RVA, increased from 386 to 471 RVU (22% increase) and peak time decreased from 5.1 to 4.2 min by the addition of 11% GL based on starch, while the final viscosity decreased from 372 to 343 RVU (8% decrease) (Fig. 4). The decrease in final viscosity indicates reduced amylose retrogradation in the presence of GL. The viscosity profile of rice starch was slightly different from that of maize starch. The addition of 11% GL caused its peak viscosity to increase by 30% from 250 to 323 RVU and the peak time to decrease from 6.3 to 4.3 min. Unlike maize starch, the final viscosity of the rice starch was increased from 250 to 269 RVU (8% increase) in the presence of 11% GL (Fig. 5).

Gel firmness data (Fig. 6) indicated that the maize starch gel (control) was significantly firmer, 0.59 N, than the rice starch gel 0.1 N (control) at $p > 0.0001$. As expected, starch gels stored at 4 °C showed significantly higher firmness values (0.37 N) than at ambient temperature (0.32 N) ($p = 0.0022$) (Fig. 5). The starch gel also became softer with increased levels of added GL. The 6 and 11% GL additions showed lower insignificant gel firmness values, and 6 and 21% caused significant reductions on gel firmness ($p = 0.0049$) (Fig. 5).

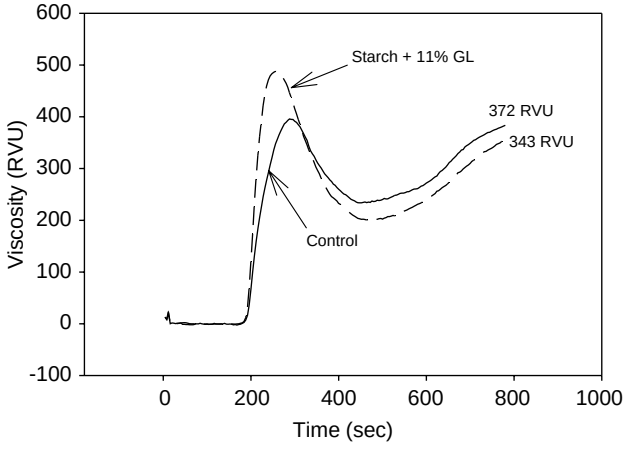

Fig. 4. RVA pasting properties of maize starch.

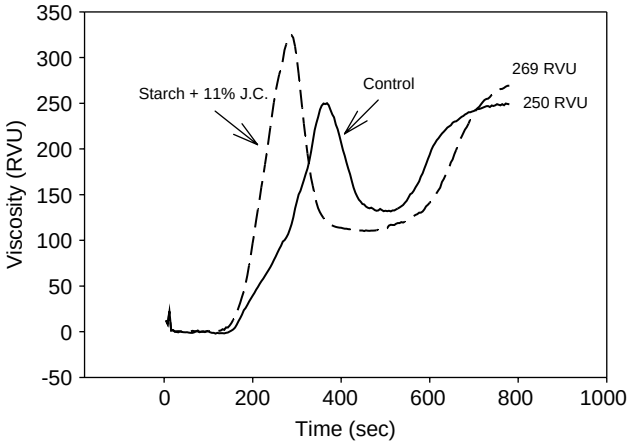

Fig. 5. RVA pasting properties of rice starch.

The effect of GL on the retrogradation properties of starch was also examined by monitoring G', the shear storage modulus, after a typical pasting curve. In this case, the magnitude of G' reflects the degree of structural strength as amylose molecules reassociate during retrogradation. Amylopectin molecules also reassociate and crystallize to contribute structural strength during retrogradation, but their large size relative to amylose greatly slows their molecular mobility (Stauffer, 2000). Therefore, amylopectin retrogradation occurs over a time scale of several days, and is not seen in the rheology experiments finished at 15 h. The effects of amylose retrogradation for maize and rice starch, as a function of GL, are shown in Figs. 7 and 8 where G' is also reported as a function of time immediately following the pasting profile for both starches.

For the concentrations shown, it can be seen that the addition of GL to maize starch reduced the magnitude of retrogradation, except at the lowest concentration, 0.1%. It is not clear why this very low concentration of GL increased G' relative to the maize starch control, and more work needs to be done to fully explain this phenomenon. When GL was added up to 0.3%, the retrogradation of maize starch was reduced quite significantly. Apparently, the added GL interferes with the

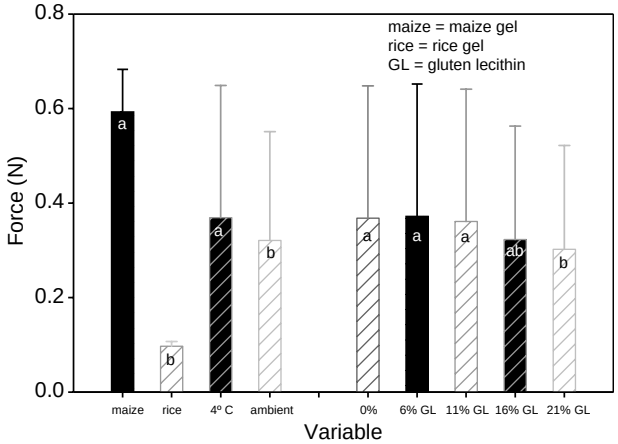

Fig. 6. Combined data main effect of starch type, storage temperature, and percent added GL on maize and rice gel firmness.

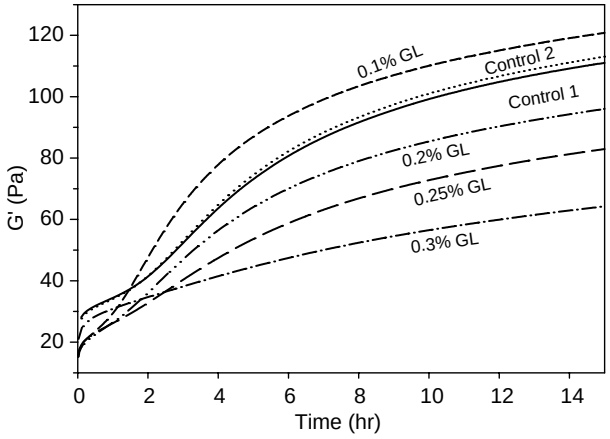

Fig. 7. Effect of GL on G' of maize starch gel.

ability of amylose to form a three-dimensional network. Concentrations higher than 0.3% (not shown) did not further reduce G'; in fact, G' began to rise again. With the concentrations above 0.3%, the shape of the individual curves was very similar, and increases in G' were due primarily to the increase of the initial value. This most likely reflects the effect of increasing solids concentration; eventually added GL and starch will take up excess water and increase viscosity (and consequently G').

Fig. 8 shows the retrogradation behavior for common rice starch at four concentrations of GL. Amylose retrogradation in general is greatly decreased in rice starch compared to maize starch and it does not gel nearly as strongly (note the vertical scale change in Fig. 7 relative to Fig. 8). With the significant decrease in the amount of amylose, the only observable effect of added GL is an increase in G' due to the raised solids concentration. This is identical to the behavior described for the maize starch blends at a GL concentration $>0.3\%$. This behavior is consistent with the RVA results with rice starch where the final viscosity increased by 8% on the addition of 10% GL.

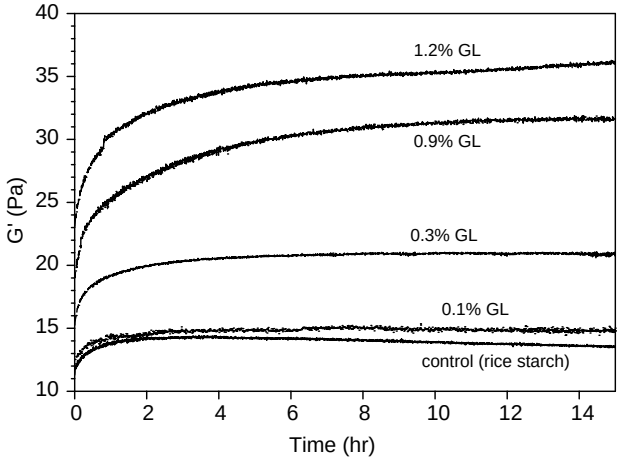

Fig. 8. Effect of GL on G' of rice starch gel.

4. Conclusion

Jet-cooked GL blend reduced the retrogradation of the amylose in maize starch significantly at all storage temperatures as measured by DSC. Overall, on storage at 4 °C more maize amylose retrograded relative to that at ambient temperature and at −20 °C. On the other hand, rice starch showed no clear correlation between amylose retrogradation and the amount of GL added, very likely this is due to the lower amylose content of rice starch. Jet-cooked GL blend absorbed twice as much water as jet-cooked gluten, which may correlate with its ability to interfere with amylose and prevent the formation of a stronger gel. The two starches showed significant differences in their final viscosities, gel firmness, and the overall correlation between gel characteristics in the presence of GL. Rheological testing of the gels demonstrated that small amounts ($<0.5\%$ by weight) of GL blend had a significant impact on the retrogradation properties of the maize starch, but the same behavior was not seen when blended with the normal rice starch with a lower amylose content.

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